AD-A125 582 INFRARED INSPECTION OF NEW ROOFS(U) COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH C J KORHONEN DEC 82 CRREL-SR-82-33 1/1

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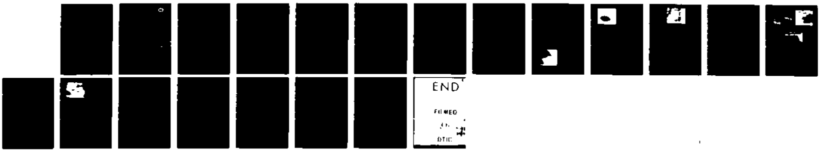

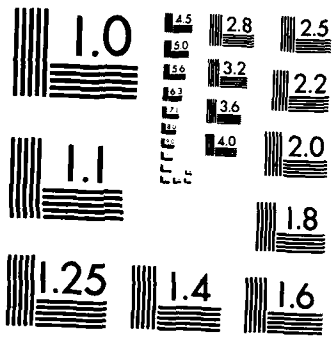
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Special Report 82-33

December 1982

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Infrared inspection of new roofs

Charles J. Korhonen

83 03 09 018

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Special Report 82-33	2. GOVT ACCESSION NO. AD-A125502	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INFRARED INSPECTION OF NEW ROOFS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Charles J. Korhonen		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project 4A762730AT42 Task D, Work Unit 015
11. CONTROLLING OFFICE NAME AND ADDRESS Office of the Chief of Engineers Washington, D.C. 20314		12. REPORT DATE December 1982 13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Buildings	Moisture
Infrared detection	Roofs
Infrared photography	Thermal insulation
Infrared signatures	Thermovision

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The feasibility of using infrared cameras to detect wet insulation during the typical 1-year warranty period for new Army roofs was studied. Both the ability to gain moisture and the manner of wetting of insulations were of major concern. Although some insulations take on moisture much slower than others, 8 to 10 months usually is ample time for most insulations to absorb enough moisture to be detectable by an infrared camera. However, the early signs of this moisture as seen with the infrared camera differ with insulation type. Basically, boards of slower-wetting cellular plastic insulations initially wet at their perimeters,

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20. Abstract (cont'd)

whereas highly absorbent fibrous insulations tend to wet more or less uniformly. An infrared camera is well suited for finding the typically small and sometimes irregularly shaped wet areas on a new roof. A specification incorporating this technology should now be tested.

PREFACE

This report was prepared by Charles J. Korhonen, Research Civil Engineer, Construction Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded under DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Task D, Cold Regions Design and Construction, Work Unit 015, Infrared Inspection of New Roofs Prior to Acceptance.

W. Tobiasson and B. Coutermarsh of CRREL technically reviewed this report.

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INTRODUCTION

This report discusses the feasibility of using an infrared camera as an inspection tool for detecting wet insulation in newly constructed built-up roofing systems. It also provides guidance for surveying new roofs and recommends that this technology initially be implemented in Corps of Engineers specifications and inspection procedures on a test basis.

The perfect application of a built-up roofing system probably has never been achieved. It is not uncommon in the Army for a 20-year roof to be replaced well before it is 10 years old. Nor is it uncommon to hear of a recently constructed roof containing blisters, wrinkles and leaks. Although it may not be possible to prevent all roofing problems, recent developments in nondestructive testing offer the potential of minimizing the effects of roof leaks by locating areas of wet insulation. If a leak can be detected during the warranty period then the contractor will become obligated to repair it rather than the owner having to pursue expensive remedial measures a few years later.

Nuclear, capacitance and infrared techniques all can find wet insulation, which often leads to the location of defects in roofs. (Such devices, however, cannot solve other roofing problems, such as blisters and wrinkles.) But, because newly formed wet areas are likely to be small, the infrared technique is preferred. It can "see" every square inch of a roof, whereas the nuclear and capacitance "grid" techniques only examine a small area of the roof at each grid point.[2]

Infrared cameras have been quite successful in finding wet insulation[7] because of their ability to detect variations in surface temperature. It is well established that the roof surface over wet insulation is normally at a different temperature than that over dry insulation[3]. Wet areas develop rather rapidly in insulations like fiberboard, fibrous glass and perlite. An infrared camera would undoubtedly be useful for detecting incipient roof leaks in these rapid-wetting materials. However, many roofs are now being built with cellular plastic insulations such as urethanes and

isocyanurates. These materials take on moisture at a lower rate. Consequently, it would take somewhat longer before an infrared camera would be able to detect a wet area in a roof containing cellular plastic insulation.

The objective of this project was to determine if an infrared camera could be used to find wet insulation during the customary 1-year warranty period of newly built roofs containing cellular plastic insulations.

LABORATORY STUDIES

Laboratory studies by Tobiasson and Ricard[8] showed that the rate of moisture gain can vary considerably among insulations. They showed that cellular plastic insulations take on moisture much slower than do the fibrous and porous types, and that moisture thermally affects each insulation differently. Laboratory results for perlite and urethane insulations are presented in Figure 1.

In Figure 1a we see that a moisture content of 2% by volume reduces the thermal resistance of perlite to 80% of its original dry value. In contrast, the same percent reduction in urethane's insulating ability does not occur until it has a moisture content of 5%. The relative time required to achieve these water contents under combined temperature and moisture gradients is shown in Figure 1b. It is seen that a day and a half was required to induce a moisture content of 2% into the perlite, whereas

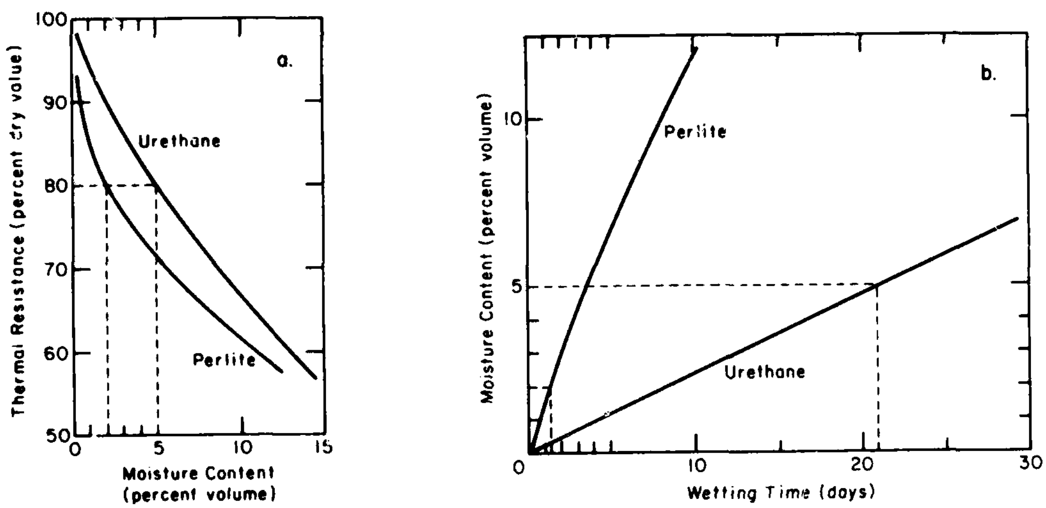

Figure 1. Relationship between the thermal insulating value and the rate of moisture gain for perlite and urethane insulation.[8]

it took 21 days for the urethane to become 5% wet. Thus urethane not only gains moisture slower but requires more water to produce the same percent change in thermal effect on a roof.

Although these laboratory steady-state results illustrate relative wetting rates, they probably differ from actual wetting rates, since field wetting conditions are not steady-state.

FIELD STUDIES

A study of how field conditions affect the wetting rates and the moisture patterns generated in cellular plastic insulations was achieved by thermographically examining many roofs containing urethane and polystyrene insulations.[1 4 5 6] These studies demonstrated that new roofs can be imperfect, and that an infrared camera can be used to find the resultant wet insulation. In addition, they revealed that moisture patterns in cellular plastic insulated roofs are often different and can be somewhat misleading in comparison to those patterns manifested in roofs containing a more moisture-absorbent insulation. The following examples illustrate some of the moisture patterns that were encountered during these field studies.

Boardstock patterns

Work with infrared cameras has shown that it takes a fair amount of experience before one can consistently distinguish thermal patterns caused by moisture from patterns that are not related to moisture. Figure 2 illustrates a rectangular thermal pattern that has come to be recognized as a fairly reliable indication of wet insulation. A thermogram is essentially a heat picture, where the brighter areas are hotter than the

Figure 2. Thermogram of wet fiberglass insulation.

Figure 3. Thermogram of a rectangular boardstock-type pattern that was not caused by moisture.

darker areas. Wet insulation normally appears hotter than dry insulation to an infrared camera when infrared surveys are conducted at night. In this instance, several 3-ft-wide by 4-ft-long boards of wet fibrous glass insulation are evident as bright rectangles.

The tendency for insulation to become wet one board at a time can probably be attributed to two factors: the ability of an individual board to wick water laterally and the presence of gaps and occasional bitumen dams between insulation boards. If bitumen dams are present the migration of water from board to board is restricted. Experience has shown that this wetting phenomenon occurs most often in roofs containing fibrous glass. This suggests that wicking action plays a dominant role in creating the rectangular boardstock patterns, as fibrous glass insulation is highly moisture-absorptive.

Although boardstock patterns are usually strong indications of moisture, Figure 3 shows a rectangular pattern that was caused by an extra thick built-up membrane, and not by the anticipated wet insulation. The roof in Figure 3 contained urethane insulation.

Thermal framing

Because plastic insulations wet more by vapor diffusion than by wicking, there is little tendency for progressive board-by-board wetting to occur. Water is more apt to move in the gaps between the boards than to soak into them.

An example of this wetting behavior is shown in Figure 4, where several boards of urethane insulation are thermally outlined.[9] Without the benefit of core samples to verify the supposed condition, this thermal

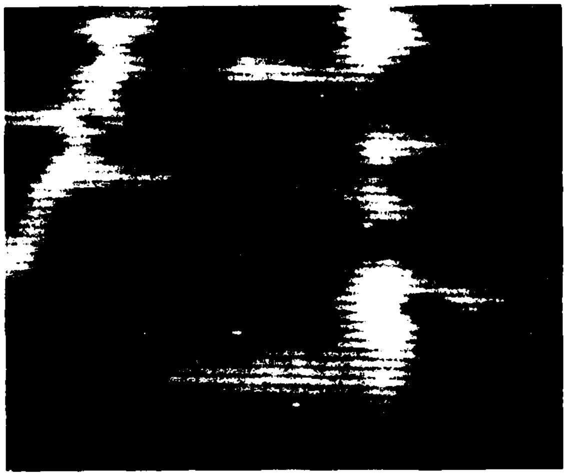

Figure 4. Thermogram of wet urethane insulation. Note that the edges gain moisture first as opposed to the entire board getting wet as seen in Figure 2.[9]

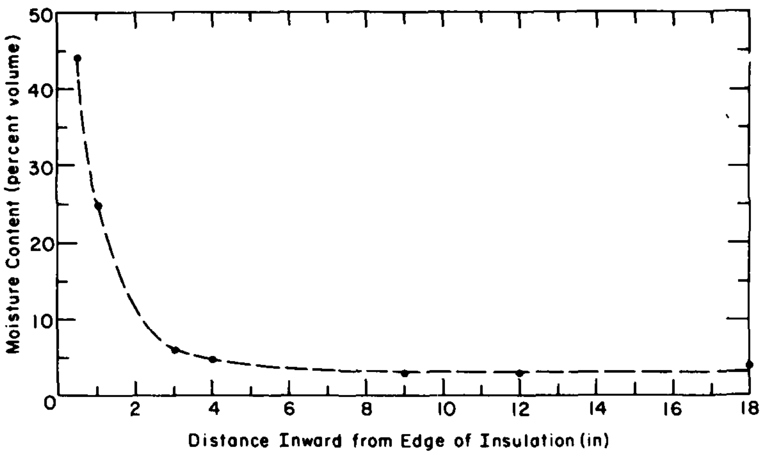

Figure 5. Relationship between moisture content and the distance away from the edge of a board of urethane insulation shown in Figure 3.[9]

framing could be attributed to either excess heat loss through the insulation joints or to wet insulation. Past surveys have revealed such bright lines to result from extra heat escaping through the insulation joints, even when the insulation there was dry.

In this case, several samples taken at varying distances from a seam between two boards of insulation confirmed that the thermal framing found there was primarily caused by wet insulation. Also, in addition to verifying the presence of moisture, this coring operation demonstrated the ability of urethane to resist lateral moisture migration. Figure 5 shows

that the volumetric water content dropped from over 40% near the edge of the board to 10% about 2 inches into the board (that moisture would have been distributed more uniformly in a fibrous insulation).

Figure 4 was taken on a 14-month-old roof which reportedly contained enough water in some roof locations to nearly fill a core sample hole up to the level of the built-up membrane.[9] Although this roof was relatively new it was observed to be almost completely water-covered on two occasions prior to the time the Figure 4 thermogram was taken.[5] These should not be typical wetting conditions since most new roofs have slope to drain. If a roofing flaw is present on a sloped roof, the moisture entering that roof is more likely to be in small amounts. Due to the unusually large amount of water in this roof, the moisture pattern in Figure 4 is not considered to be representative of early moisture signs for a typical new roof.

Early moisture signs

Figure 6 shows two thermograms of a roof area taken 5 months apart. Their differences suggest that the amount of moisture there had changed. Core samples and electrical resistance probe readings indicate that essentially no additional water had entered this area between the two surveys.[5] It is evident that thermogram 6a revealed few signs of moisture and that thermogram 6b, taken during the warranty's tenth month, showed clear signs of moisture. The extent of wet insulation detected with an infrared camera during each survey is shown by the spray paint markings in the Figure 6c daytime photograph. The five small areas outlined with a solid line of paint represent the wet insulation detected in May. The much larger area outlined by a dotted paint line indicates the wet insulation "seen" five months later.[5] (Had it not been for the core samples taken, most of the insulation in Figure 6a would have been thought to be dry in May. This demonstrated the importance of taking core samples.)

The reason that less wet insulation was detected with the infrared camera during the first survey (Fig. 6a) was that most of the water was located near the bottom of the insulation. Electrical resistance probe readings in thermally dark areas in Figure 6a showed the upper three-fourths of the insulation to be dry but the lower quarter to be wet. In the thermally bright areas of Figure 6a, similar readings showed the upper portions of the insulation to be wet.[5]

As discussed earlier, moisture must change the surface temperature of a roof before an infrared camera can detect it. Wet/dry temperature dif-

a. May 1979 thermogram.

b. October 1979 thermogram.

c. October 1979 photograph. The solid spray-painted lines depict the extent of wet insulation detected in May while the dotted lines depict the October boundaries.

Figure 6. Two thermograms and a daytime photograph of a roof containing wet urethane insulation. Note how much more moisture is detected by the October 1979 survey.

ferences can and do occur during both the heating and nonheating seasons of the year. In the summertime, because wet insulation absorbs and stores more solar heat than dry insulation, the roof surface over wet insulation remains warmer than that over dry insulation for much of the night. During the winter, the extra building heat that is conducted through wet insulation, relative to that through dry insulation, produces a warmer roof surface there.

During the summertime, when Figure 6a was taken, very little heat from the sun was able to penetrate through the upper dry insulation and warm the water at depth. The deep water remained essentially at the same temperature as the adjacent dry insulation, and as a consequence, the infrared camera had difficulty detecting it. But in those areas of Figure 6a where the water was near the surface, heat from the sun was readily conducted into it, making it detectable to the infrared camera. The second survey was also conducted during a nonheating time of year. But this time the moisture was more uniformly distributed from the bottom toward the top of the insulation, which allowed the infrared camera to "see" it with little difficulty (Fig. 6b).

We can see that during the nonheating season it can be more difficult to thermographically detect water deep in a roof than water just under the surface. In cold weather, this deep water should be easier to detect because water increases heat losses wherever it is in the insulation relative to that lost through dry insulation. But because it may not always be possible to schedule a survey for cold weather, detection limitations during warm weather are an important consideration.

Moisture surveys on roofs containing cellular plastic insulations should be conducted as late as possible in the 1-year warranty period because

1. Cellular plastic roof insulations wet slowly.
2. The bottom portion of the insulation may wet first and moisture located there is difficult to detect.
3. Eventually some moisture will migrate toward the top of the insulation where it is easier to detect.

The ninth or tenth month of a 1-year warranty period is the recommended time to conduct roof moisture surveys. This provides time for an insulation to gain a detectable amount of moisture as well as time to assess survey results and to notify the contractor of remedial work before the warranty ends.

Thermal mottling

Thermal mottling, which is characterized by the light and dark areas seen in Figure 7, can be caused by differences in the moisture content in the insulation[6] or by variations in the color and/or thickness of the gravel surface.[4] Generally, a close visual examination at the time of the survey will reveal whether one of the above or some other surface condition

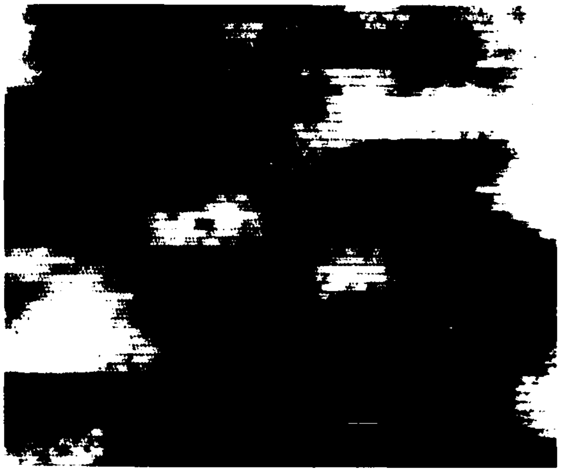

Figure 7. Thermogram of a typical mottled pattern which can be caused by differences in insulation moisture contents or by variations in the color and/or thickness of the gravel surface.

has created the mottling. A few representative core samples from the light and dark areas are recommended as final verification.

CORE SAMPLES

Core samples are considered to be the "cornerstone" of infrared roof inspections. Without ground truth, one cannot be certain whether or not wet insulation has been found. Variations in gravel, flood-coat or membrane thickness can create thermal patterns that resemble the early signs of wet insulation. Therefore it is important that a few core samples be taken in conjunction with a detailed visual examination to determine the cause of each type of thermal anomaly and to determine if other flaws are present elsewhere on a roof. For example, samples should be taken from boardstock patterns, mottling, thermal framing and other light and dark areas. Because there are many reasons for anomalous moisture readings, a half-dozen samples or more are commonly required per roof.

INFRARED CAMERAS

Not all commercially available infrared cameras are considered to be sensitive enough for surveying new roofs. Experience has shown that where the insulation is quite wet, most hand-held infrared cameras give similar results. But for warranty inspections where the insulation is just beginning to get wet, a temperature sensitivity to a fraction of a degree means the capability of detecting a small but important thermal disturbance on a roof. Of all the hand-held infrared cameras that have been investigated by CRREL, systems with the capabilities of the AGA Thermovision 750 and the

Inframetrics Model 525 are considered to be the most appropriate. The AGA system was used for this project.

GRID SURVEYS

Nuclear and capacitance techniques, although capable of detecting wet insulation, were not evaluated in this project. Their major drawback is that they are grid surveys which do not "see" all of the roof. For example, a nuclear survey taken on a 5- by 5-ft grid only "sees" about 8% of the roof.[2] Because of this, grid surveys are more likely to overlook small areas of wet insulation than are infrared surveys. The need for accuracy is obvious. A small flaw that is missed during a warranty survey can turn into a long-term maintenance and energy liability. However, should an infrared camera not be available, a grid survey would be of some value because it is more accurate than a visual examination.

IMPLEMENTATION

The use of an infrared camera as a new roof inspection tool has been demonstrated to be feasible. Now this technology should be tested on a few roofs before it is incorporated into Army specifications and inspection procedures. I am not in a position to decide how this should be done, but the discussion provided below may help.

Commercial surveys

Several commercial firms currently offer roof moisture surveys. Contracting for services of this nature should enable the Army to obtain the needed warranty inspections. However, to use such services a detailed roof survey specification would be needed to assure high quality results.

Specifications

There appear to be three alternatives for incorporating moisture surveys into Army roofing specifications:

1. Add nothing to the present roofing specifications.
2. Add a section in the roofing specifications to state that roof moisture surveys and core samples shall be conducted.
3. Add a section in the roofing specifications to state that roof moisture surveys and core samples may be conducted.

The surveys of new roofs for this project were done under the conditions of the first alternative where no changes were made to the roofing specifications. This arrangement functioned quite well. Warranty repairs

were received on two roofs that were found by the infrared camera to be defective. On both of these roofs there was reason to suspect construction-related defects, but, because there was no evidence, visual or otherwise, to support that contention no repairs had been made. The owners' claims were just not specific enough to be able to direct any repairs. However, when faced with the evidence from an infrared survey, the contractors returned to make repairs.[5] [6]

Problems in obtaining warranty service have resulted in the past when a warranted roof was cut into without the issuer of the warranty being notified. Most roof warranties specifically exclude responsibility when a roof is abused by unacceptable penetrations. To avoid these potential problems the roofing contractor was notified by letter and by phone before any new roof was surveyed in this project. Such contact may not always be possible but it is certainly advisable.

To avoid communication problems it may be better to add something in the specifications to put the contractor on notice at the beginning of the contract.

The second alternative listed above provides this notice to the contractor by stating in the specifications that roof moisture surveys and core samples <u>shall</u> be used. But by *saying "shall" it is possible* that the Army will become legally obligated to have such a survey conducted. I do not recommend this approach. The third alternative, which replaces the word "shall" with "may," is preferred since it alerts the contractor, gives the Army the option of conducting a moisture survey, and avoids potential legal problems should a survey not be done.

The following is a list of basic requirements that should be added to Army roofing specifications to serve as this notice:

1. The specifications should state that a roof moisture survey <u>may</u> be conducted and that core samples <u>may</u> be taken.
2. The method by which patches will be made should be specified. (A procedure developed at CRREL is widely used in North America at this time.)
3. The contractor should still be liable for defects until the end of the warranty period. A roof survey once done should not release him from this obligation.
4. Costs of the survey will be the responsibility of the Army.
5. Results of the survey will be made available to the contractor.

6. If wet insulation or other workmanship-related deficiencies are discovered, the contractor shall make repairs as directed by the contracting officer. (It will be necessary to define "wet" insulation. Insulation can reasonably be assumed to be wet if it contains a sufficient amount of moisture to reduce its insulating value to less than 80% of its dry value.)

As a suggestion, the following paragraph could be inserted into the roofing specifications:

> "To be sure that the subject roof contains no moisture or other construction defects, the contracting officer or his appointed representative may conduct a roof moisture survey before expiration of the warranty period. Although such a survey, once done, does not release the contractor from any contractual obligations it may serve as a basis for final acceptance of the roofing system. Several samples of the roofing system may also be taken in conjunction with these surveys to determine moisture contents of various roofing components. Insulation that contains sufficient moisture to reduce its insulating value to less than 80% of its initial dry value shall be considered to be wet and unacceptable. Core sample holes shall be patched by the roof surveyor according to practices currently accepted by the roofing industry. If wet insulation or some other construction-related defect is found, corrective action shall be taken by the roofing contractor as directed by the contracting officer or his appointed representative. The cost of the moisture surveys will be the responsibility of the government, and the results of the survey will be provided to the contractor."

It is recommended that a roofing specification be drafted to include the above suggestions and then be tested on a number of Army roofs that are to be built in the near future. CRREL should be able to participate in this test phase.

SUMMARY

It is apparent from the problems that frequently occur on relatively new roofs that current inspection techniques are not adequate to detect construction defects during the warranty period.

An infrared camera, with its ability to "see" every square inch of a roof, is well suited for detecting incipient roof leaks, especially in absorbent insulations. Cellular plastic insulations, on the other hand, present some extra difficulties. They wet slowly, and as a consequence the bottom portions tend to wet first. At that location moisture can be more difficult to detect than moisture near the top surface. Also, the insulation seams become wet before the rest of the board does. This produces moisture patterns in cellular plastic insulations that differ from those generated in the more absorbent insulations. By being aware of these limitations one can be quite successful at finding moisture in cellular plastic insulations before the end of the 1-year roof warranty. Infrared surveys should be conducted during the latter one-third of the warranty period to allow time for detectable levels of moisture to enter the insulation and for timely notification of the contractor. Several core samples are needed from each roof surveyed for verification purposes.

The recommended approach for implementing new roof inspections in the Army is to insert some additional information into present roofing specifications. The information added should place the contractor on notice that a roof moisture survey <u>may</u> be used as a check on his work. The word "may" places the contractor on notice without committing the Army to a survey. Specifications with this information in them should be tested on several new roofs to prepare a way for Army-wide implementation of this technology.

I am convinced that the Army can greatly benefit by conducting infrared inspections on its new roofs. Finding defects in new roofs while they are the responsibility of the roofing contractor can save the Army money and many future maintenance headaches.

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U.S. GOVERNMENT PRINTING OFFICE 1983 A-2294/328

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